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INTERTEMPORAL SPECULATION WITH A RANDOM DEMAND IN AN EXPERIMENTAL MARKET

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SOCIAL SCIENCE WORKING PAPER 446

October 1982

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ABSTRACT: The behavior of three markets with speculators is studied. Each market is for commodities that can be carried forward one period by two speculators. Demand in the first period is stationary from year to year and demand in the second period is randomly determined. The question posed by the research is the reliability of rational expectations models relative to autarky models, in explaining market behavior. The result is that the rational expectations model is more accurate.

Speculation in markets presents some of the most interesting of scientific challenges. Almost all of the behavioral sciences can become involved in the analysis, as is clear from the major features of the phenomena. For example, individuals observe prices and the choice behavior of other individuals and appear to form assessments about the course of coming events. Economic analysts tend to model this process of assessment formation as subjective probability formation and apply Bayes law to capture the essence of the process. However, learning and expectations formation are studied in other disciplines, so the economic models necessarily inherit the criticisms of Bayes law held by behaviorists from other fields. In addition, the assessments result in decisions; and the most tractable model of the decision process, and thus the model used by economic analysts, involves an application of the expected utility hypothesis which is frequently dismissed in related disciplines as having no behavioral content at all. The competition among speculators fosters a simultaneous interaction of decisions that might be captured by the law of supply and demand. In the case of speculation, however, models of the supply and demand process are difficult to close and solve unless one postulates that the law of supply and demand operates in a manner consistent with speculators' expectations. This latter feature, which is added by the application of the principle of rational expectations, operates as though the individuals are able to individually solve the system by application of the law. Substantial dimensions of controversy are added because speculators are not ordinarily trained as economists, cannot articulate such a law, and for the most part even seem to be unaware that such a law might be operative. So, many would claim without reservation that the theory is worthless.

*The financial support of the National Science Foundation, The Caltech Program for Enterprise and Public Policy, the Guggenheim Foundation, and the Center for Advanced Study in the Behavioral Sciences at Stanford is gratefully acknowledged.

In this paper the behavior of three experimental markets with speculators is reported. The objective of the study is to determine whether the abstract rational expectations models are reliable at all in economic environments more complicated than those previously studied and, if so, to what degree. Speculation over time under conditions of stationary demand has been studied by MILLER/ PLOTT/ SMITH (1977); HOFFMAN/PLOTT (1981); PLOTT/ UHL (1981); FORSYTHE/ PALFREY/ PLOTT (1982); WILLIAMS (1979); and SMITH/ WILLIAMS (1982). Speculation with uncertainty is studied in PLOTT/ SUNDER (1982). The markets studied in this paper involved uncertainty and time, simultaneously, which had only been studied separately in previous experiments. The uncertainty involves a degree of complexity beyond that studied in Plott and Sunder. The demand functions are not perfectly elastic as they were in the Plott and Sunder experiments. If demands are not perfectly elastic, prices are generally sensitive to small changes in supply and their information content can thereby be "contaminated."

The parameters and experimental design are outlined in the next section. The structure of applicable models is outlined in the third section. The data are reviewed in the fourth, and the conclusions are presented in the last section. As it turns out, the models still perform with substantial accuracy even in the more complicated environment.

EXPERIMENTAL DESIGN AND PARAMETERS

Three experiments were conducted. Subjects were recruited from California Institute of Technology (CIT), University of Southern California (USC), and University of California at Los Angeles (UCLA), and had no previous experience in experimental markets. Each experiment lasted approximately three hours including instructions and training with the random process used to determine demand.

The general format was the same as that introduced by MILLER/ PLOTT/ SMITH (1977). The market consisted of a series of years, each of which had two periods (blue and yellow). Two traders had the capacity to purchase units in the blue period and carry them forward to the yellow period in hope of selling them at a profit. No other agent had this capacity. Units could not be carried forward by other agents, and the traders could only carry forward from the blue period to the yellow period of a given year. Inventories could not be held between years. It was as though the product could be produced in both the blue and yellow periods but would spoil after the yellow period. Thus the traders had a special role within these special markets.

The markets were organized as oral double auctions. Buyers and sellers respectively tendered bids and offers orally to an auctioneer. Only the best bid or offer remained open. Thus all bids, offers, and contracts were observed by all participants. See PLOTT (forthcoming) for details of this form of market organization.

Individual redemption values and costs are given in Table 1.

TABLE 1: Individual Redemption Values and Costs*

Buyer	X Demand Functions 1st unit	2nd unit	3rd unit	Z Demand Functions 1st unit	2nd unit	3rd unit	Seller	Cost 1st unit	2nd unit	3rd unit
2	5.40	3.00	2.40	7.20	7.00	5.00	1	4.60	6.60	7.00
4	5.60	4.60	3.20	7.20	6.40	6.20	3	5.60	5.80	7.20
6	5.20	4.40	2.80	7.20	6.80	4.80	5	4.80	6.80	8.00
8	5.80	4.20	3.40	7.20	6.00	5.40	7	5.40	6.00	7.80
10	4.80	4.00	2.60	7.20	6.60	5.20	9	5.00	6.40	7.60
12	5.00	3.80	3.60	7.20	5.80	5.60	11	5.20	6.20	7.40

*The two traders had no exogenously imposed redemption values or costs.

These aggregate to the demand and supply functions shown in Figure 1. Neglecting units possibly carried forward, the supply function was the same in both the blue period and the yellow period of any given year, and it was also constant across years. Demand in the blue period was as shown in the figure and it was constant across the blue period of all years. Demand in the yellow period was determined by a random variable. With probability equal to one-third the demand function is the one labeled X in the figure and, with probability two-thirds, is the one labeled Z. That is, with one-third probability the demand was constant between the blue and yellow periods, and with two-thirds probability the demand increased in the yellow period. Of course, speculative activity by traders will alter the effective demand in the blue period and supply in the yellow.

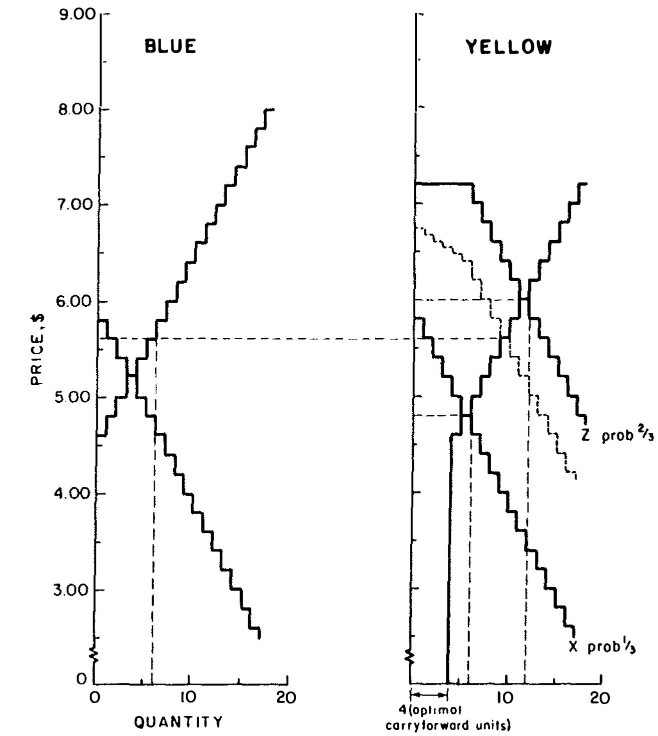


FIGURE I MARKET DEMANDS, MARKET SUPPLY AND THE RATIONAL EXPECTATIONS MODEL

During the markets the random mechanism used to determine the demand in the yellow period was a bingo cage. Prior to the beginning of the market, subjects observed from 100 to 150 draws from the bingo cage, which had 36 balls numbered from one to thirty-six. If a ball numbered from one to twelve was drawn the event was X and otherwise it was Z. The probabilistic model, prob(X) = 1/3, prob (Z) = 2/3, accurately modeled the proportion of X and Z draws in all demonstrations. The draws made prior to the beginning of each yellow period were from the same cage used in the demonstration and the event, X or Z, was publicly announced.

MODELS AND HYPOTHESES

Since the underlying random event is publicly announced, the application of the rational expectations model is the same as a Walrasian model in which no learning from prices exists. The model is described by the following equations.

(1) $D_X(P_B) + T = S(P_B)$

(2) $D_s(P_Y(s)) = S(P_Y(s)) + T, \ s \in \{X,Z\}$

(3) $P_B = \text{prob}(X)P_Y(X) + \text{prob}(Z)P_Y(Z)$

T = carry-forward | s = state
P_B = price in blue period | $D_s(\cdot)$ = demand function in state s
P_Y = price in yellow period | $S(\cdot)$ = supply function

Equations (1) and (2) are statements of the law of supply and demand for a given level of speculative activity T. Equation (2) also acknowledges that the price in the yellow period is dependent on the outcome of the random event which determines the value of the random variable s. Equation (3) is the rational expectations principle. Traders, in the absence of risk aversion, will adjust carry-forward to the point at which expected profits are zero.

If prob(X) and prob(Z) are assumed to be 1/3 and 2/3, then the solution to these equations for the parameters of the experiment is:

$$P_B = 5.60 \qquad P_Y(s) = \begin{cases} 4.80 \text{ if } s = X \\ 6.00 \text{ if } s = Z \end{cases}$$

$$T = 4$$

Implicit in the above model is a concept of temporary or short-run equilibria. Equations (1) and (2) for a fixed level of carry-forward determine market prices. Implicitly these equations also define a concept of temporary efficiency. According to the general model these prices will have a predictable influence on the carry-forward, and the carry-forward will have an influence on prices from those that would exist without carry-forward.

The null hypothesis is that speculation is ineffective. The formal description is derived from equations (1) and (2) and the assumption T = 0. Price predictions in the null hypothesis are:

$$P_B = 5.20, \ P_Y(X) = 5.20, \ P_Y(Z) = 6.40.$$

Equations one through three have implications in addition to price and quantity, about the efficiency with which the systems operate. The efficiency of a market reflects the degree to which the process exhausts the gains from exchange. If the traditional concepts of consumer and producer surplus are applied as measures of the gains from exchange and if no risk aversion is present, then the system operates at 100 percent efficiency if the expected earnings of all participants are at a maximum. Formally, the expression for expected earnings at 100 percent efficiency is:

$$(4) \quad \max_{X_B, X_Y(s), T} \left[\left\{ \int_0^{X_B} D_B(x)dx - \int_0^{X_B+T} S(x)dx \right\} - \sum_s \text{prob}(s) \left\{ \int_0^{X_Y(s)+T} D_s(x)dx - \int_0^{X_Y(s)} S(x)dx \right\} \right], \ s \in \{X,Z\}.$$

The first order conditions to (4) can be interpreted as equations (1), (2), and (3) above. So system efficiency can be viewed as a measure of the success of the rational expectations model. Since the demand and supply functions $D(\cdot)$ and $S(\cdot)$ are accessible as the redemption schedules and cost schedules, respectively, maximum efficiency for the system is equivalent to maximum total earnings of agents.

In markets without uncertainty the efficiency measurements are easily computed. The introduction of random variables complicates matters unless many markets and market years are available. The actual earnings of individuals depend upon the realization of the random event, so ex ante "poor" decisions may be very profitable ex post. Some problems of this nature can be avoided by an application of partial equilibrium analysis as opposed to the general equilibrium analysis implicit in (4). Some measures which reflect these problems will be introduced below in the results section.

RESULTS

The time series of all transactions of all periods for all three experiments are in Figures 2, 3, and 4. Contract prices are shown in the order in which they occurred. Shown in the figures are also the number of units carried forward. Table 2 provides average price data for all periods of all experiments. These are listed along with the predictions of the model, given the outcome of the random process, and (i) given the actual carry-forward, (ii) the autarky prices of zero carry-forward, and (iii) rational expectations prices of the optimal carry-forward of four units. The values of (iii) are shown as dashed lines in the figures. The values of (i) and (ii) were not graphed because the resulting figures would be too cluttered.

RESULT 1: The null model is rejected along all dimensions in favor of the rational expectations model.

Carry-forward except period 1 of the UCLA market is always above zero. The likelihoods of the data, given the model, are in Table 3 for the last periods of occurrence for each state for each market. In the last periods of two of the three experiments P_B is (significantly)

FIGURE 2 TIME SERIES OF CONTRACT PRICES, SPECULATION EXPERIMENT AT CIT

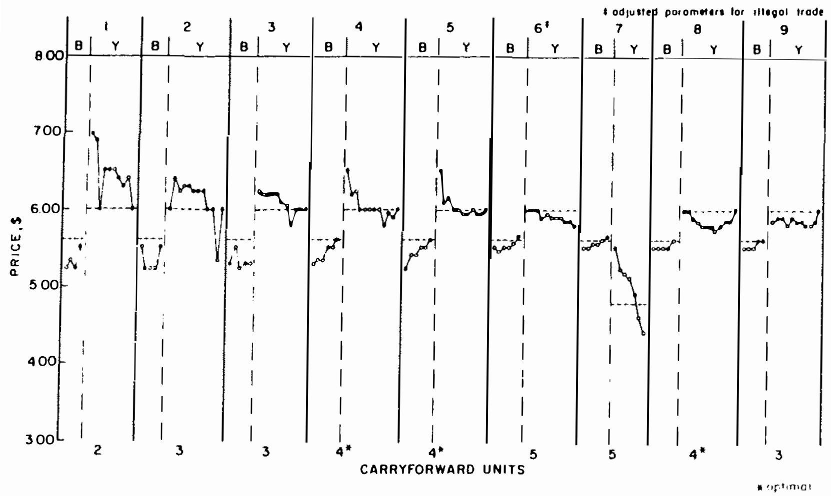
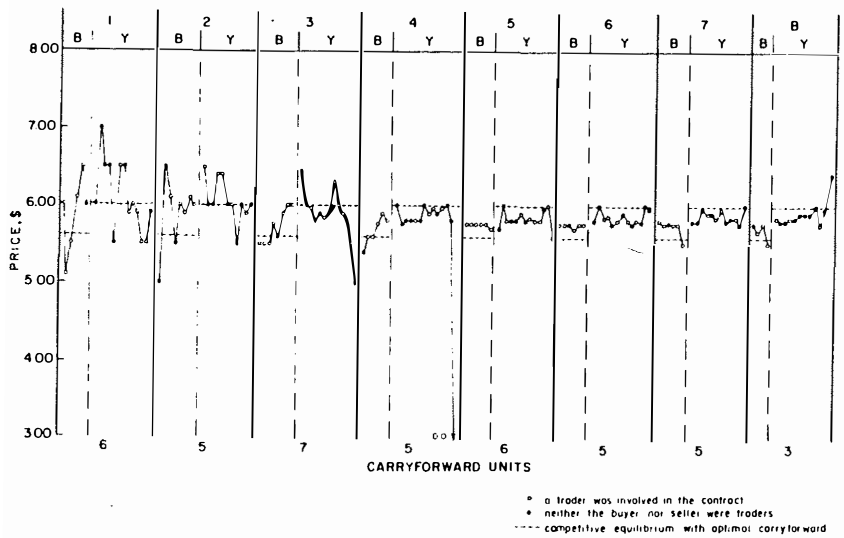
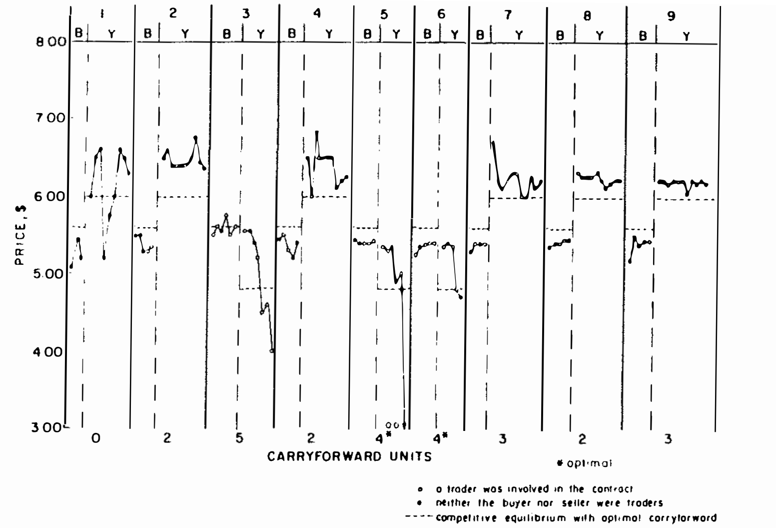


FIGURE 3 TIME SERIES OF CONTRACT PRICES, SPECULATION EXPERIMENT AT USC



closer to 5.60 than to 5.20 and in the remaining UCLA market the models were tied. Prices in the last yellow period for which Z occurred are never closer to the null hypothesis than to the rational expectations predictions. When the event is X, the rational expectations model is better in the CIT market and autarky is better in the UCLA market. The few times of an occurrence of X in the UCLA

FIGURE 4 TIME SERIES OF CONTRACT PRICES, SPECULATION EXPERIMENT AT UCLA



market probably accounts for this latter statistic because markets take time to adjust. In both the CIT and USC markets the rational expectations model is a better predictor than the autarky model in almost all periods. In the UCLA market the two models are about tied if number of periods is the measure.

TABLE 2: Average Prices and Predicted Prices

a. California Institute of Technology

	Market Year and Period					
	1B	1Y	2B	2Y	3B	3Y
Average	5.34	6.45	5.35	6.11	5.33	6.09
Given CF	5.40	6.20	5.50±.10	6.10±.10	5.50±.10	6.10±.10
Autarky	5.20	6.40	5.20	6.40	5.20	6.40
4-Unit CF	5.60	6.00	5.60	6.00	5.60	6.00
	4B	4Y	5B	5Y	6B	6Y
Average	5.43	6.05	5.44	6.05	5.53	5.92
Given CF	5.60	6.00	5.60	6.00	5.70±.10	5.90±.10
Autarky	5.20	6.40	5.20	6.40	5.20	6.40
4-Unit CF	5.60	6.00	5.60	6.00	5.60	6.00
	7B	7Y	8B	8Y	9B	9Y
Average	5.56	4.99	5.52	5.87	5.54	5.86
Given CF	5.70±.10	4.70±.10	5.60	6.00	5.50±.10	6.10±.10
Autarky	5.20	5.20	5.20	6.40	5.20	6.40
4-Unit CF	5.60	4.80	5.60	6.00	5.60	6.00

TABLE 2 (continued)

b. University of Southern California

	Market Year and Period					
	1B	1Y	2B	2Y	3B	3Y
Average	5.87	6.09	5.89	6.06	5.72	5.87
Given CF	5.80	5.80	5.70±.10	5.90±.10	5.90±.10	5.70±.10
Autarky	5.20	6.40	5.20	6.40	5.20	6.40
4-Unit CF	5.60	6.00	5.60	6.00	5.60	6.00
	4B	4Y	5B	5Y	6B	6Y
Average	5.68	5.88*	5.74	5.83	5.74	5.85
Given CF	5.70±.10	5.90±.10	5.80	5.80	5.70±.10	5.90±.10
Autarky	5.20	6.40	5.20	6.40	5.20	6.40
4-Unit CF	5.60	6.00	5.60	6.00	5.60	6.00
	7B	7Y	8B	8Y	9B	9Y
Average	5.72	5.87	5.66	5.92		
Given CF	5.70±.10	5.90±.10	5.50±.10	6.10±.10		
Autarky	5.20	6.40	5.20	6.40		
4-Unit CF	5.60	6.00	5.60	6.00		

c. University of California at Los Angeles

	1B	1Y	2B	2Y	3B	3Y
Average	5.25	6.16	5.39	6.48	5.58	4.97
Given CF	5.20	6.40	5.40	6.20	5.70±.10	4.70±.10
Autarky	5.20	6.40	5.20	6.40	5.20	5.20
4-Unit CF	5.60	6.00	5.60	6.00	5.60	4.80
	4B	4Y	5B	5Y	6B	6Y
Average	5.37	6.39	5.41	5.18*	5.35	5.20
Given CF	5.40	6.20	5.60	4.80	5.60	4.80
Autarky	5.20	6.40	5.20	5.20	5.20	5.20
4-Unit CF	5.60	6.00	5.60	4.80	5.60	4.80
	7B	7Y	8B	8Y	9B	9Y
Average	5.38	6.21	5.41	6.22	5.40	6.17
Given CF	5.50±.10	6.10±.10	5.40	6.20	5.50±.10	6.10±.10
Autarky	5.20	6.40	5.20	6.40	5.20	6.40
4-Unit CF	5.60	6.00	5.60	6.00	5.60	6.00

*Trader failed to sell a unit. Note: CF = carry-forward

The next result is typical of experimental economics. The variance of the prices in the final periods is so low that the predictions of any model taken as the null hypothesis tested against the composite alternative of any other point, will be rejected. Nevertheless the results should be reported for completeness.

TABLE 3: Likelihoods of Sample Which Gives Rational Expectations and Autarky Calculated for Last Periods of Each State and Each Market

	CIT	USC	UCLA
Blue	3.4×10^{40}	1.1×10^{14}	1
Yellow (Z)	more than 10^{100}	2.4×10^{22}	6.3×10^{23}
Yellow (Y)	1.17	X never occurred	5.84×10^{-4}

The numbers are the ratios a/b:

$$a = (2\pi)^{-n/2}\exp\left[\left(-\frac{1}{2\sigma^2}\right)\sum_{i=1}^{n}(\rho_i - s_1)^2\right] \qquad b = (2\pi)^{-n/2}\exp\left[\left(-\frac{1}{2\sigma^2}\right)\sum_{i=1}^{n}(\rho_i - s_2)^2\right]$$

n = sample size

σ^2 = sample variance

ρ_i = individual prices in sample

s = predicted price by:

(s_1) rational expectations model

(s_2) autarky model

RESULT 2: The null hypothesis that the prices are equal to the rational expectations price can be rejected if tested against the composite alternative hypothesis of all other prices.

In the last periods t-tests were performed. The null hypothesis that prices were those predicted by the rational expectations model is always rejected at the .01 level of significance.

The temporary equilibrium model, equations (1) and (2), parameterized for the actual carry-forward is remarkably accurate. This suggests that the law of demand and supply is operative and that part of the error of the rational expectations model develops because the carry-forward is short of the predicted quantity. On average in the last two years of all experiments, three units carry forward rather than the predicted four units.

RESULT 3: The null hypothesis, that last-period prices are at a temporary equilibrium, can be rejected in only a few of the yellow periods. In all other periods it cannot be rejected.

In Table 4 the t ratios are given for all periods. As can be seen, the hypothesis can be rejected at the .01 level in only a few periods. In addition, in some periods there is no error at all in the temporary equilibrium model.

The final observation is related to equation (3) and the implied subjective probability of event X being one-third. The motivation of the model is that subjective expected value of prices in period yellow should equal those in period blue. If we assume that ex post frequencies equal subjective probabilities, then we get the following result.

TABLE 4: Partial Equilibrium t-Statistics for All Periods of All Experiments

Group	Periods	B t	B n	Y t	Y n
CIT	1	1.0154	4	2.4398	10
	2	0.8165	5	0	12
	3	1.6059	5	0	11
	4	3.5603*	6	0.9381	12
	5	3.2637	6	1.0187	11
	6	2.5560	6	0	10
	7	1.8926	6	1.3621	7
	8	4.0000*	5	7.7128*	12
	9	0	5	7.7821*	11
USC	1	0.3481	6	2.2170	13
	2	0.5634	8	0.7099	11
	3	1.0124	8	0.7212	13
	4	0	6	0	13
	5	7.1714*	6	0.9589	13
	6	0	6	0	12
	7	0	6	0	12
	8	1.0153	4	1.7148	12
UCLA	1	0.4804	3	1.5269	9
	2	0.2182	5	7.3251*	10
	3	0.5258	6	0.7412	7
	4	0.5571	5	2.4000	10
	5	19.0000*	5	3.9726*	5
	6	9.0094*	5	3.8579*	5
	7	0.7947	4	0.1723	11
	8	0.5345	5	1.0000	10
	9	0	5	0	11

*Would reject at better than 0.01.

RESULT 4: Prices weighted by ex post relative frequencies do not satisfy the rational expectations equation (3).

With only three observations, statistics make no sense; but the three data points we have support the conclusion. The average across periods of average blue-period prices and the average across periods of average yellow-period prices are reported for each market in the following two-tuples: for CIT (5.45,5.93); for USC (5.75,5.87); for UCLA (5.39,5.79). In all cases the expected value as reflected by observed frequencies indicates that prices are higher in the yellow period than in the blue period.

Experiences with the behavior of experimental markets would lead to caution in accepting the above analysis as evidence in support of a rejection of the rational expectations model. Markets take time to adjust and the reported averages involve periods of disequilibrium prices. Exactly how such disequilibria are reflected in the averages is not clear. It is interesting to note, however, that the event X never occurred in the eight periods at USC. The market adjustment is very close to what would be expected if prob(X) = 0. The prediction is $P_B = P_Y = 5.80$ and carry-forward should equal five units. Notice that in periods 5, 6, and 7 the data conform almost exactly to this prediction.

The second qualification turns on concepts of risk aversion. If risk aversion is present, only three units or less should be carried forward. The prices should then be those dictated by a carry-forward of three units.

RESULT 5: The carry-forward behavior of all markets is consistent with risk aversion.

In the final year of all markets, three units are carried forward. Thus, the negative implications of Conclusion 4 may simply reflect risk aversion. Future experiments could control for this hypothesis by building in some profit given the predicted carry-forward.

Efficiency numbers are in Table 5, but these are not direct derivations from (4). The experiment at USC provides an interesting example inherent in the application of a stochastic general equilibrium measure like (4) to evaluate the performance of only a few market periods. In the USC market the bad (X) state never occurred. Carry-forward was substantial and approximated that which would be carried forward if the prob(Z) = 1. Since Z always occurred, the earnings were above expectations, given other aspects of the market performance. The four measures below are attempts to cope with the problem.

The decisions of speculators are not the only determinant of market efficiency. Learning and market disequilibria can both affect efficiency and both of these are sensitive to the interactions between the blue and yellow markets. The two measures developed below reflect the behavior of a single (partial) market, parameterized as a partial equilibrium, to minimize the influence of the other market. The measures also reflect the information at the time of decision.

(5) Partial market efficiency (blue) $\equiv PME_B(T) \equiv$

$$\frac{\left[\begin{matrix}\text{earnings from blue period}\\ \text{consumption}\end{matrix}\right] + V(T)T - \left[\begin{matrix}\text{cost of blue period}\\ \text{production}\end{matrix}\right]}{\max\limits_{X_B} \int_0^{X_B} D_B(x)\,dx - \int_0^{X_B+T} S(x)\,dx + V(T)T}$$

V(T) = approximated minimum value necessary to carry forward T units,

T = units actually carried forward.

TABLE 5: Market Efficiency (%)

		CIT				USC				UCLA			
		Partial Market Efficiency	General Efficiency 1	General Efficiency 2	Carry Forward	Partial Market Efficiency	General Efficiency 1	General Efficiency 2	Carry Forward	Partial Market Efficiency	General Efficiency 1	General Efficiency 2	Carry Forward
1	B Y	62 99	70	88	(1,1)	71 98	96	92	(5,1)	92 88	39	75	(0,0)
2	B Y	93 99	86	95	(1,2)	90 96	96	93	(2,3)	100 100	73	94	(1,1)
3	B Y	93 100	87	97	(2,1)	96 94	94	85	(2,5)	100 99	98.7	63*	(3,2)
4	B Y	100 100	100	100	(1,3)	62 87	85	66	(3,2)	92 100	73	93	(2,0)
5	B Y	94 99	99	99	(1,3)	100 99	99	99	(4,2)	100 78	83	-36*	(2,2)
6	B Y	100 90	91	81	(1,4)	100 82	83	61	(3,2)	100 100	100	100*	(2,2)
7	B Y	100 99	99	69*	(2,3)	100 99.6	99.6	99	(5,0)	93 100	87	97	(1,2)
8	B Y	100 100	100	100	(1,3)	93 99	85	95	(3,0)	100 100	73	94	(0,2)
9	B Y	100 96	84	91	(2,1)					100 100	87	98	(1,2)

*The low demand event, X, occurred.

The numerator is consumer plus producer surplus that actually resulted in the blue period when the price of the carry-forward is approximately the minimum constant price which would induce that carry-forward. The denominator is the maximum that the total value of earnings could be, given the carry-forward.

(6) Partial market efficiency (yellow) $\equiv PME_Y(T) \equiv$

$$\frac{\begin{bmatrix}\text{earnings from yellow period}\\ \text{consumption}\end{bmatrix} - \begin{bmatrix}\text{yellow period}\\ \text{production costs}\end{bmatrix}}{\max\limits_{\substack{X_Y(s)\\ s\varepsilon[X,Z]}} \int_0^{X_Y(s)+T} D_s(x)\,dx - \int_0^{X_Y(s)} S(x)\,dx}$$

Definition (6) is similar to (5) with one major exception. The realization of the random variable is known before period yellow begins, so the efficiency of the system reflects the outcome. The opportunity cost of units carried forward is zero so the consumption of these units contributes to utility (earnings) but not costs. The denominator is the maximum earnings that can occur, given carry-forward and the outcome of random event.

The final measure is an attempt to combine the two ex post, partial measures in (5) and (6) into an ex post general equilibrium measure consistent with the essence of (4).

(7) General efficiency$_1$ $\equiv GE_1(s,T)$ =

$$\frac{\begin{bmatrix}\text{earnings from}\\ \text{blue period}\\ \text{consumption}\end{bmatrix} + \hat{V}\cdot T^A - \begin{bmatrix}\text{cost of blue}\\ \text{period}\\ \text{production}\end{bmatrix} + \begin{bmatrix}\text{earnings from}\\ \text{yellow period}\\ \text{consumption}\end{bmatrix} - \begin{bmatrix}\text{cost of yellow}\\ \text{period}\\ \text{production}\end{bmatrix}}{\int_0^{\hat{X}_B} D_B(x)\,dx - \int_0^{\hat{X}_B+\hat{T}} S(x)\,dx + \hat{V}\hat{T} + \int_0^{X_Y^0(s,T^A)+T^A} D_s(x)\,dx - \int_0^{X_Y^0(s,T^A)} S(x)\,dx}$$

$\hat{V}$ = expected price in yellow period, given an optimal carry-forward as calculated from (4),

$\hat{X}_B, \hat{T}$ = optimal values calculated from (4),

X_Y^A, T^A = actual value observed.

The measure has aspects of double counting, depending upon the philosophy of time that one wishes to apply. The quantity $\hat{V} \cdot T^A$ in the numerator is in a sense the "utility" obtained by traders in period blue from the purchase of a lottery. This value is added to the consumers' surplus from period blue consumption. Yellow period consumption actually involves the realization of the lottery with no subtractions or "loss" for the occurrence of the unfortunate event. One could argue that the units are not comparable. An alternative and very reasonable measure is (8) with $\hat{V} \cdot T^A$ removed from the numerator and $\hat{V}\hat{T}$ removed from the denominator, and the carry-forward in the denominator postulated to be the optimum. Of course if the carry-forward is greater than the optimum and the good state occurs, this measure of efficiency can exceed 100 percent.

(8) General efficiency$_2$ $\equiv GE_2(s,T)$ =

$$\frac{\begin{bmatrix}\text{earnings from}\\ \text{blue period}\\ \text{consumption}\end{bmatrix} - \begin{bmatrix}\text{cost of blue}\\ \text{period}\\ \text{production}\end{bmatrix} + \begin{bmatrix}\text{earnings from}\\ \text{yellow period}\\ \text{consumption}\end{bmatrix} - \begin{bmatrix}\text{cost of yellow}\\ \text{period}\\ \text{production}\end{bmatrix}}{\int_0^{\hat{X}_B} D_B(x)\,dx - \int_0^{\hat{X}_B+\hat{T}} S(x)\,dx + \int_0^{\hat{X}_Y^s+\hat{T}} D_s(x)\,dx - \int_0^{\hat{X}_Y^s} S(x)\,dx}$$

RESULT 6: Neither the presence of randomness nor the existence of speculators decreases partial market efficiency. The existence of speculators increases general market efficiency.

Both the blue and yellow partial market efficiencies grow to nearly 100 percent as the number of periods increases. These measures are typical of markets which are converging to an equilibrium. As the markets adjust and agents acquire familiarity with the prices and trading technology, the markets tend to exhaust the (temporary) gains from exchange. The general market efficiency numbers are more difficult to evaluate. These numbers tend to exceed the autarky efficiency of 75 percent. Unfortunately, in these data we do not have a frequent occurrence of the low demand event and on two occasions, a trader failed to resell a unit, thereby substantially reducing efficiency. Nevertheless, both efficiency measures reflect the improved efficiency due to speculators. GE_1 tends to be relatively (to GE_2) sensitive to carry-forward and will fall substantially as the carry-forward deviates from the theoretical optimum of four units. Even with this sensitive measure, efficiency tends to exceed autarky expectations.

CONCLUSIONS

The rational expectations model is more accurate than the autarky model. Even though the model has errors when applied without adjustment or risk aversion, no alternative model does so well in explaining the behavior of these markets. Certainly in view of the controversy about the component theoretical parts of the model, the use of Bayes law, the expected utility hypothesis, the principle of rational expectations, and the like, the model is surprisingly accurate. In this latter respect the data from these markets should be added to the data generated from the behavior of less complicated markets in providing support for the rational expectations class of models over the current set of alternative models.

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